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**Title:- Volume assessment of the effect of obturators on facial form following surgery for head and neck cancer using stereophotogrammetry.**

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**Running Title:- Volume assessment of obturators on facial form.**

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## ABSTRACT

**Purpose:** To determine if the technique of stereophotogrammetry could be used to determine the effects of obturators on facial contour in relation to the measurement of facial volumes.

**Materials and Methods:** Stereophotogrammetry images were recorded from 20 subjects with and without their obturators in place. These were converted into a stereolithographic format and overlaid. Registrations were made using the tissues on the normal areas of the face. Difference images were created which enabled surface areas and volumes to be calculated. To assess repeatability of measurement two readings were recorded on each of two separate registrations. Data analysis between the sets of readings was undertaken using correlation coefficients and paired t-tests. Coefficients of repeatability were also calculated.

**Results:** A comparison of readings for the surface areas showed the method of measurement was repeatable with no significant differences between the two repeated readings for registration 1 ( $p=0.977$ , coefficient of repeatability =  $101\text{mm}^2$ ), registration 2 ( $p=0.085$ , coefficient of repeatability  $106\text{mm}^2$ ), and the mean of the two readings for registration 1 compared with registration 2 ( $p=0.355$ , coefficient of repeatability  $103\text{mm}^2$ ). Similar results were found for the volume measurements with no significant differences between the repeated readings for registration 1 ( $p=0.862$ , coefficient of repeatability  $229\text{mm}^3$ ), registration 2 ( $p=0.2$ , coefficient of repeatability  $209\text{mm}^3$ ), and the mean of the

two readings for registration 1 compared with those for registration 2 ( $p=0.131$ , coefficient of repeatability  $339\text{mm}^3$ ). There was a range of volumes that appeared to have been restored by the obturators which was statistically significant ( $p < 0.0005$ ).

**Conclusions:** Stereophotogrammetry is reliable in assessing the effects of obturators on facial form. In the sample of subjects, obturators generally appeared to be effective in supporting facial tissues following surgical resections of the maxilla and therefore contribute in some degree to the restoration of facial appearance.

**Key Words:** Stereophotogrammetry, oncology, oral, rehabilitation, obturator

## INTRODUCTION

The surgical removal of diseased tissue in individuals diagnosed with head and neck cancer can have profound effects, most obviously on oral function, swallowing and speech. In the case of surgical removal of part of the maxilla, the resulting intraoral defect may be of a substantial size. Although there are surgical techniques which may be used to replace the resected hard and soft tissue structures, alongside oral implantology with either fixed or removable prostheses to restore masticatory function <sup>1</sup>, it is still the case that for many individuals such techniques may not be viable or clinically indicated. In these circumstances rehabilitation of the surgical defects is undertaken by the construction of conventional prosthodontic appliances such as removable obturators that replace the teeth and missing tissue. These are often challenging for the patient to wear, as, due to their size and often compromised retention, they may not be entirely stable in function, particularly if the patient is edentulous in the maxilla.

In addition to masticatory and oral function, it is apparent that the resection of the diseased tissues affects facial form and contour. Although it would appear that conventional removable obturators do have effects on restoring facial appearance after surgery to some degree, it has been difficult to assess this apart from forming opinions based subjectively on what the individuals report or the clinicians observe.

Imaging techniques to look at facial contour have been used for many years. In particular previous work by Coward et al, have looked at the use of laser

scanning to assess landmarks and dimensions on the face and ears. <sup>2,3,4,5</sup>

Furthermore, comparisons have been made between laser scanning, magnetic resonance imaging and computerized tomography both in the assessment of objects of standard form <sup>6</sup>, and prosthetic ear models. <sup>7</sup> However, all of these techniques either require specialized equipment or need the subjects to remain still for a period of time while the imaging process is undertaken.

Stereophotogrammetry overcomes these concerns to capture images of objects three dimensionally. The technique involves recording separate photographic images by cameras mounted in different positions in relation to the left and right sides of the face from which three dimensional surface images can be produced. The equipment is easily portable. Due to short shutter speeds, images can be captured instantaneously which makes it much more straightforward to use than other imaging techniques, particularly on elderly subjects. The resulting images can be processed in a variety of ways to display the face. For example, the technique has been used to report on basal facial surface symmetry. <sup>8</sup>

Stereophotogrammetry has also been used to assess facial morphology on adults with unilateral cleft lip and palate <sup>9</sup>, and the effects of orthodontic treatment undertaken by rapid maxillary expansion. <sup>10</sup> In relation to the rehabilitation of individuals with hemifacial microsomia, a stereophotogrammetry technique has been used to predict the position and size of an artificial ear on the face. <sup>11</sup>

In previous preliminary work <sup>12</sup> the concept of using a stereophotogrammetry technique to capture facial form following surgery for head and neck cancer was explored. From its use on a single subject, it was reported that it was likely that

the technique could be used to assess volume changes from wearing obturators in such subjects. In the present study the technique was refined further, particularly in relation to how registration of the overlaid images was undertaken and then applied to a larger group of subjects, all of whom had received surgical resections in the maxillary region. Therefore, the initial purpose of the present study was to determine if the technique of stereophotogrammetry and methodology to overlay images of the subjects with and without the obturator in place would enable reproducible measurements of the surface area and volume of the affected region of the face to be made. If this could be shown to be consistent and reproducible then it would be possible to determine, on the same sample of subjects, the effects of conventional removable obturators on facial contour, by measuring the volume changes with and without the prostheses in place. In this way it would be possible to determine much more objectively the effect of conventional removable obturators on restoring facial form and contour than has been possible to assess in the past.

## **MATERIALS AND METHODS**

Subjects were identified from three units in England and Scotland. The subjects were recruited to the study if they had received resections for a range of lesions affecting primarily the maxillary region. Ethical approval was secured from Kings College Hospital Research and Development Committee, Guys Hospital Research Ethics Committee and Tayside Committee in Medical Research Ethics (NHS National Research Ethics Service). All subjects were given appropriate information about the study and provided written consent. A stereophotogrammetry 3D image capture and analysis system (Dimensional Imaging – Glasgow, UK) was used to map the face. The mapping involved recording a photograph of the facial tissues by the use of four mounted linked cameras to capture simultaneous pictures of the subject. The subjects were seated and instructed to look straight forward at an object placed in a fixed position between the cameras on the left and right sides. The camera set up was calibrated using a grid which has been described and illustrated previously.<sup>12</sup> The system has been found, in relation to recording and overlaying images, to be accurate to a resolution of approximately 0.5mm - the image capture system has an error value of < 0.2mm.<sup>12</sup> One set of images was recorded with the subject wearing their maxillary obturator and the second set when they had removed it. All stereophotogrammetry images were recorded by the same individual who had been fully trained and was highly experienced at using the technique on a regular basis in clinical practice. The dimensional imaging software programme allowed the three dimensional images to be assembled from the data recorded by the individual cameras. The images were converted into a stereolithographic format which stored the three dimensional information.



A specific software programme (Cloud – [www.robins3D.co.uk](http://www.robins3D.co.uk)) was developed to measure the differences between overlaying stereolithographic images by registering areas of the facial tissues that were stable. To assess these differences and the reproducibility of the process the same two assessors worked together at all times initially to reach agreement in relation to setting up the overlaid images for analysis. Subsequently the two individuals together assessed the reproducibility of the difference measurements themselves on the color coded difference images that were created. One of the assessors was the individual who also recorded all of the stereophotogrammetry images.

In the first instance the images were loaded for each subject with and without the obturator. These images were rotated such that they were orientated for analysis in the full face view (face on).<sup>5</sup> Areas of the face were then identified for registration of points on the face so that the two images could be compared. Essentially this involved identifying areas of the face that were judged to be stable and would not change between the two images. Primarily the areas were located on the forehead, mid face and lower face. These areas are shown in yellow on Fig 1. Some of the normal areas of the face were excluded from the registration as it was judged that these points would be insufficiently stable between the images from the subjects wearing the obturator and removing it – these areas included the hair, neck, orbits and ears which were identified by shading them in orange (Fig 1). The images could be rotated to ensure that areas for registration were accurately outlined and displayed for reference (Fig 1). In relation to the area of the resection itself a preliminary outline of the defect area

on the face was made in the first instance, based on the history of the subject and the photographs of the face both with and without the obturator. After a preliminary analysis to ensure that this area would be certain to include all of the defect which had been restored by the obturator, a final outline of the defect area was made and the area also shaded in orange (Fig 1). Registration between the two images could then be made on the remaining normal areas of the face (shaded in yellow which formed the majority of the surface of the image – Fig 1). Registration between the two surfaces was achieved using an iterative closest point algorithm.<sup>13,14</sup> At each iteration, 500 points on the normal, yellow shaded part of the surface (Fig 1) were randomly picked for calculating the next registration error correcting vector, and the correction vector applied.

A color coded difference image was then calculated to show the differences between the superimposed images of the subjects with and without their obturators in place. The scale of the difference image was set up to give maximum resolution but also to ensure that difference values were not beyond the range such that they became outliers and therefore excluded from the analysis. The distribution of depth differences was calculated by creating a 64 bin histogram from small patches (pixels) of the difference surface. In most subjects this could be undertaken by using incremental bin widths of 0.25mm which generated a scale of  $\pm 8$  mm. However, in a small number of cases where the defects seemed to be particularly extensive and in which the obturators appeared to be having a large effect on facial form, the bin widths were changed to a lower resolution of 0.5 mm which produced a scale of  $\pm 16$  mm. The generated pixels were stored in the bins which indicated various depths where

change took place when the obturator was inserted compared to when it was not present. Examples of the color coded difference images are shown in Fig 2. On these images the areas of the defect were outlined and the software calculated volume differences where the surface of the face had changed between inserting and removing the obturators.

On the difference image the defect was outlined separately on two occasions and volume measurements recorded. In addition, the whole process was repeated on a separate set of registrations. This gave a total of four surface area and four volume measurements for each subject – two from the first registration and two from the second. Paired t –tests were carried out to assess whether there were differences between the two measurements from Registration 1 (Readings 1 and 2), Registration 2, (Readings 1 and 2), and between the mean of the two measurements from Registration 1 and Registration 2. Correlation coefficients and coefficients of repeatability were also calculated for the same group of measurements. A p value of  $< 0.05$  was considered to be significant.

Following analysis of the repeated readings, final difference values of volume were calculated for each subject based on the mean of the 4 separate readings. A statistical analysis from a comparison of the positive versus negative components that contributed to the net volume differences was undertaken by means of a paired t-test based on a null hypothesis that the obturator was having no effect on restoring facial volume.

## RESULTS

A total of 20 subjects were recruited to the study, 10 male and 10 female all of whom had undergone surgical resections in the maxillary region. The ages of the subjects at the time of the imaging ranged from 40-84 years with a mean of  $68 \pm 11$  years. The subjects had initially presented with a range of lesions including squamous cell carcinoma, basal cell carcinoma, chondrosarcoma, osteosarcoma, adenoid cystic carcinoma, leiomyosarcoma and ameloblastoma. Subjects received a range of treatments depending on their diagnoses with some receiving radiotherapy and / or chemotherapy in addition to the maxillary surgical resections that were undertaken on all of them. There was obvious variation between the subjects in relation to the magnitude of the maxillary resection, its location and whether any natural teeth were able to be retained, however all 20 subjects required a removable prosthetic obturator to restore their form and oral function in relation to appearance, mastication and speech. Similarly, there was variation between the periods since each of the subjects had received surgery, how recently their current obturators had been made and the number they had worn since the resections were originally undertaken.

Examples of the effects of the obturators in restoring facial form are shown in Fig 2 in which the facial photographs themselves have been modified such that the individuals cannot be identified, but the full face images were used for the actual stereophotogrammetry mapping of the face. The first subject (Fig 2A) received a left sided maxillary resection and the difference image is displayed with a scale of  $\pm 8$  mm. In the areas of the face where the anatomy was normal, differences on the overlaid images were very minimal indicating that good registrations of

the two images had been obtained. However, the overlaid images with and without the obturator in place showed modest, but clear differences in facial form in the area where the obturator was present. Larger differences are shown in the second subject (Fig 2B) who had also received a left sided maxillary resection but in this case the difference image is shown on a scale of  $\pm 16$  mm indicating a much larger change of facial contour when the obturator was in place. It can be seen that the difference area appeared to be more extensive over the face than the subject in Fig 2A and not only does it extend over a greater surface area, but also the depth changes on the difference image are much more profound.

For each of the registrations, two readings were recorded for the surface area of the restored defect, which was outlined by the two assessors working together. It was apparent for registration 1 that in all subjects the two readings were very similar. This was also the case for the two readings recorded in registration 2. For the two readings in registration 1, the Pearson correlation coefficient was 0.99, and there were no significant differences between them (paired t -test,  $p = 0.977$ ). The coefficient of repeatability was  $101\text{mm}^2$  compared with a mean surface area for the 20 subjects of  $1404\text{mm}^2$ . For the two readings in registration 2, the Pearson correlation coefficient was also 0.99 and again there were no significant differences between them (paired t -test,  $p = 0.085$ ). The coefficient of repeatability was  $106\text{mm}^2$  compared with a mean surface area for the 20 subjects of  $1415\text{mm}^2$ . Finally, for the mean of the two readings in registration 1 versus the mean of the two readings in registration 2, the Pearson correlation coefficient was again 0.99 and again there were no significant

differences between them (paired t –test,  $p = 0.355$ ). The coefficient of repeatability was  $103\text{mm}^2$  compared with a mean surface area for the 20 subjects of  $1409\text{mm}^2$ . The mean of the two readings for registration 1 is displayed alongside the mean of the two readings for registration 2 in the clustered bar chart shown in Figure 3.

Having outlined the area of the restored defect, the volumes of these areas were calculated. For each of the registrations, two readings were recorded for the volume of the restored defect, which had been outlined by the two assessors working together. Like the surface area outlines it was apparent for registration 1 that in all subjects the two readings were very similar. This was also the case for the two readings recorded in registration 2. For the two readings in registration 1, the Pearson correlation coefficient was 0.99, and there were no significant differences between them (paired t –test,  $p = 0.862$ ). The coefficient of repeatability was  $229\text{mm}^3$  compared with a mean volume for the 20 subjects of  $5078\text{mm}^3$ . For the two readings in registration 2, the Pearson correlation coefficient was also 0.99 and again there were no significant differences between them (paired t –test,  $p = 0.2$ ). The coefficient of repeatability was  $209\text{mm}^3$  compared with a mean volume for the 20 subjects of  $5135\text{mm}^3$ . Finally, for the mean of the **two** readings in registration 1 versus the mean of the two readings in registration 2, the Pearson correlation coefficient was again 0.99 and again there were no significant differences between them (paired t –test,  $p = 0.131$ ). The coefficient of repeatability was  $339\text{mm}^3$  compared with a mean volume for the 20 subjects of  $5106\text{mm}^3$ . The mean of the two readings for registration 1 is

displayed alongside the mean of the two readings for registration 2 in the clustered bar chart shown in Figure 4.

As the four readings of volume were similar in all subjects, the final calculated volumes are shown in Fig 5 as the mean of the four separate readings (registration 1, readings 1 and 2, and registration 2, readings 1 and 2). The male subject in Figs 1A and 2A is represented as subject 16 in the bar chart and the female subject in Figs 1B and 2B is represented as subject 18. There are large volume differences between the two subjects with the obturator restoring a volume of 2668 mm<sup>3</sup> on subject 16 and 11394 mm<sup>3</sup> on subject 18. This is reflected in the scales on the difference images in Figs 2A and 2B respectively. The mean volume difference of the sample was 5106 mm<sup>3</sup>  $\pm$  SD 3232. It can be seen that there was quite a wide range of volumes that appeared to have been restored by the obturators in the different subjects. The exception was subject 7 in which there was very little effect overall. The net volumes of the restored defect areas were calculated by the software as a net value from any positive or negative differences from overlaying the two images. A paired t-test to compare the positive versus negative components that contributed to the net volume differences was highly significant ( $p < 0.0005$ ).

## **DISCUSSION**

This study has shown that the technique of stereophotogrammetry and the overlaying of images for registration does enable reproducible measurements to be made of the surface area and volume of affected areas of the face in this sample of subjects. Furthermore, in nearly all subjects the presence of the obturator was clearly affecting facial form by providing more support for the soft tissues which was reflected in the volume measurements.

The main issue arising from previous work in this area is how to measure actual changes of facial tissue and contour. Studies using imaging techniques have commonly used facial landmarks to evaluate techniques. For example, an evaluation was made of intra and interexaminer repeatability and reproducibility of soft tissue landmarks on stereophotogrammetry images of the face.<sup>15</sup> In other studies using laser scans soft tissue landmarks were used to calculate dimensional measurements on the face and ears.<sup>4</sup> There are two issues that might arise when using facial landmarks in individuals who have had maxillary resections. The first is that there may be significant effects on facial contour after surgery, with obvious asymmetry present. This might make it difficult to compare landmarks on one side of the face versus the other, a situation that might particularly become an issue if the surgical resection extends across the midline. The second is that even movements of facial landmarks do not necessarily allow objective measurements of facial contour itself to be made. What is really required is a method to calculate changes of volume in the facial tissues in different situations. This could only effectively be undertaken by using a method to overlay images of the subjects with and



without their prosthesis, registering areas of the face that are stable, and then calculating facial change in the particular area of interest where the obturator is in place.

One of the critical aspects of making a meaningful accurate assessment of the volume changes resulting from the obturators is how the two images are overlaid and registered. Developing an accurate means of undertaking this was essential. For this reason, identification of suitable areas of the face to register the images was critical. The hair, ears, neck and orbital areas were all eliminated from the registration process as there might be the potential for changes between the two sets of images. The defect area also had to be eliminated from the registration process and in all cases great care was taken by the two assessors to be certain that the final registration was made only when the whole extent of the lesion was shaded orange (in some cases when a difference image had been generated it became apparent that the two assessors may not have eliminated the defect area completely from the registration process and therefore a complete reanalysis was undertaken of the images for those particular subjects). In this way the assessors could be confident that registration of the two overlaid images of the subjects with and without the obturator in place was made by using areas of the face that were not likely to change between the two sets of photographs. The method employed by using areas of the face for registration in the present study is similar to one that has been used in a previous piece of work.<sup>16</sup> In that study volume changes in facial contour were imaged in subjects with and without artificial swellings of the cheek using a stereophotogrammetry optical three dimensional scanner. In that

system the registration of the two images was recorded on the basis of the forehead and bridge of the nose as suggested by the manufacturer since they were assumed to be three dimensionally stable, and the authors were able to demonstrate that their system was reliable and able to measure volumetric changes in facial contour.<sup>16</sup> However, the software that was developed for the present study, involving the use of an iterative closest point algorithm on a random selection of 500 points on areas designated as stable, permitted a much wider area of the face to be employed for registration (the yellow shaded areas outlined in Fig 1), compared with the study by Van der Meer et al 2014 in which only the forehead and the bridge of the nose was used.<sup>16</sup> It should be emphasized in the present study that these volume difference measurements do not require an absolute orientation as it is the relative orientation of the two objects (i.e. with and without the obturator in place), which is important. Therefore, this should bring increased accuracy, and was clearly demonstrated by the very clear outlines of where the obturator was contributing to volume changes, examples of which are shown for two subjects in Fig 2.

In the first instance it was necessary to show that the two assessors were able to outline reproducibly the area of the face over which the obturator was impacting. Visually the difference images allowed in most cases the assessors to effectively and clearly outline the defect area over which volume measurements were calculated. However, it was necessary to be sure that the readings were consistent. For this reason in the first instance correlation coefficients were calculated. These were all found to be consistently very high, both in relation to the two readings on each registration, and also as a result of when the two

readings were combined for the first registration and compared to those of the second registration. In a study of reproducibility of soft tissue landmarks on facial images obtained from a stereophotogrammetry technique, intraclass correlation coefficients were found to be good for repeated readings by two examiners.<sup>15</sup> Furthermore, in the present study paired t –tests between the repeated readings showed no significant differences in all cases.

In previous work<sup>7,17</sup>, correlation coefficients have been used to assess repeated dimensional measurements on prosthetic and natural ears. However, one criticism of using correlation coefficients alone to compare repeated measurements is that they might be considered to be misleading because even though a high correlation can be demonstrated, it does not necessarily imply that the method is repeatable.<sup>18</sup> For this reason the coefficients of repeatability were also calculated for the repeated sets of readings.<sup>18</sup> The coefficients of repeatability represent the minimum surface areas that can be measured and ranged between 101 – 106 mm<sup>2</sup> on the three sets of readings. It was apparent that 19 of the 20 subjects showed the outlined areas as considerably higher than this. Of the 19 subjects with higher readings than the coefficients of repeatability, even subjects 3 and 4 on Fig 3 had outlined areas, from the mean of each of the readings on the two registrations, of over four times the value of the coefficient of repeatability. The values ranged up to subject 18 who had a mean area reading of over twenty times the value of the coefficient of repeatability. Only subject seven had an area reading less than the coefficient of repeatability range as it appeared that the area of change resulting from wearing the obturator was very small indeed. In nineteen out of the twenty subjects the areas outlined were well above the minimum required for repeatability.

Having established that the coefficients of repeatability for the area outlined on the difference images did infer that the areas of the face that the obturators were providing support for could be interpreted clinically <sup>16</sup>, the next step was to analyze the volumes. Again, it was necessary to show that the resulting volume measurements were consistent and reproducible from the two sets of readings for each registration. Correlation coefficients in all cases were very high, and paired t-tests showed no significant differences between the readings, similar to how this has been explained for the area measurements. Again, it was felt that calculations of the coefficients of repeatability were critical to understand whether there were true volume differences from the subjects having the obturator in place as opposed to volumes less than the coefficients of repeatability which could not then be interpreted as a true difference. <sup>16</sup> The three coefficients of repeatability in relation to volume measurements ranged from 209 – 339 mm<sup>3</sup>. It would be considered unsafe to form any clinical conclusions of the effectiveness of obturators in providing facial support for any volume measurements that were below these coefficient of reproducibility values. Indeed, the coefficients of repeatability clearly reflect very low volume changes which would be most unlikely to be detected clinically. However, only one subject (number 7) had an overall defect volume smaller than this range (Fig 5). The next smallest volume change from the obturator was of a magnitude of over twice the coefficient of repeatability (Subject 3) and all others substantially higher. Again, for this reason the method of measurement was reproducible and the resulting volume changes in nineteen out of the twenty subjects were well over the minimum required for repeatability.

It was noted from the difference images on some subjects that the areas of the face that the obturator was providing support for almost certainly extended beyond the actual area of the surgical defect itself. The most likely explanation of this finding is that like any removable prosthesis, obturators may provide support to the facial tissues overlying the maxillary denture bearing areas where the natural teeth are no longer present. For example, the subject shown in Fig 2B, had a primarily left sided defect but the difference image also shows the obturator is providing some additional lip support on the right side when in place. When outlining the surface areas on the difference images, it would not have been possible to make an assessment of exactly how to separate out tissue support provided by the obturator in normal areas of the face, compared with areas where the surgical resection had been undertaken. However, it was obvious that the obturators were profoundly contributing to facial support well beyond the areas of the face overlying the normal maxillary denture bearing area.

In relation to simply observing a subject, it may not be clear exactly how the presence of an obturator provides the facial support. Although for the two subjects shown in Fig 2, the clinical photographs might suggest differences between the facial tissues with and without the obturator in place, it is difficult, simply by a visual analysis, to determine exactly where that difference is, and how large the effect. However the difference images clearly show the outline of where the obturator is contributing to facial support, and the volume differences are clear (Subjects number 16 and 18 in Fig 5). This was confirmed by the

overall analysis, in which it can be seen that in some cases the effects of the obturator appear substantial. In these cases, the obturators not only may have been of substantial size due to the extent of the surgical defect, but in addition they are clearly supporting the facial tissues significantly. It might therefore be expected that these subjects would be very reliant on the prosthesis to restore their facial appearance as well as other functions such as mastication, swallowing and speech. In only one subject did it appear that the obturator was making very little difference (Subject 7), and as mentioned earlier, the difference observed appeared to be less than the coefficient of repeatability. A method of imaging was used on subjects with unilateral maxillary defects in which the facial data was acquired from them either with or without their maxillary prostheses.<sup>19</sup> Facial landmarks were studied and the authors were able to show that displacement of some points with the obturator in place, such as the lateral and inferior points at the ala of the nose were greater on the defect side compared with the normal side.<sup>19</sup> The study concluded that the maxillary obturator prosthesis changed the facial morphology around the nose, ala and lip. The angles of the mouth were also affected on both sides horizontally but not vertically. In the present study it is likely that with the obturators in place these areas of tissue were also becoming displaced, but it has been shown more precisely the overall volume changes to the face that have resulted from this group of subjects wearing their obturator. Therefore, this study has demonstrated a way to validate a system for measuring volume changes and the resulting effects of obturators in restoring facial volume following surgical resections which has not been shown before.

It should be emphasized that it was not the objective of the present study to determine whether the obturators were able to provide a similar level of facial support to that which existed prior to the resections. To do this it would have been necessary to carry out imaging at the stage of diagnosis of the subjects before any surgical intervention was undertaken and to then make comparisons after treatment and prosthodontic rehabilitation. This was something that would not have been possible with this group of subjects in relation to how they presented at separate units across the country. Furthermore, the subjects presented with a wide variation of diagnoses which will have clearly influenced the treatment they received in relation to the resulting location and size of the maxillary defects. Similarly, it is not possible to compare, for example, one side where a resection has been undertaken with the opposite side where it has not because the location of the defects were variable and in some cases extended bilaterally. Notwithstanding this, the results show that for 19 of the 20 subjects, the obturators were having a measurable effect on facial form of the subjects to their benefit, as clearly if the obturators were not present the facial tissues would be unsupported, which in some subjects would be very profound and would almost certainly impact on their quality of life. It might in future work be possible to determine if obturators can provide ideal support for the tissues with reference to the facial contour that existed prior to treatment by imaging the subjects preoperatively at the stage of diagnosis. However, this could still be challenging not least because some of the lesions themselves may well result in distortion or change to the facial tissues before any of the surgical resections are undertaken, and therefore even at this stage of imaging the facial contour may be different to that which existed before the disease process had progressed.

## **CONCLUSION**

The development of a method of assessing the effects of obturators on facial form from stereophotogrammetry images has been shown to be reliable.

Although it is not possible in a study such as this to be certain that the obturators are restoring the exact original facial contour that existed before the surgical resections were undertaken, it is nevertheless the case that for this sample of subjects the prostheses are clearly making effective volume changes to the face when they are being worn compared to when they are not in place. Indeed, in some subjects the volume changes with and without the obturator in place were found to be profound. This confirms that as well as their other effects in relation to mastication, swallowing and speech, obturators do seem to be effective in restoring facial appearance to some degree where there have been significant resections of diseased tissue. It is not yet known whether these specific effects of the obturator can be related to the impact on subjects' quality of life following surgery. This requires further study.

## **ACKNOWLEDGEMENTS**

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## FIGURE LEGENDS

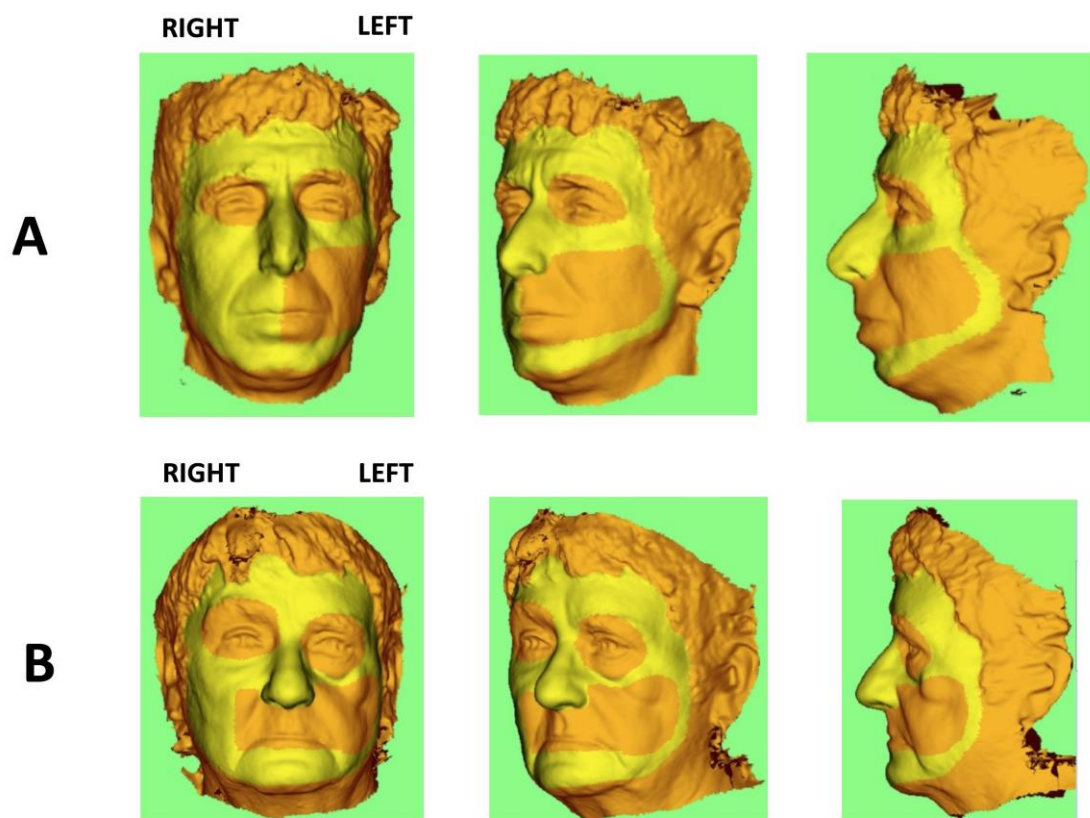
Figure 1. Examples of the registration process for images of subjects with and without the obturators in place. The areas outlined in yellow show the parts of the face that were used for the registration process. In both subjects the area of the defect, as well as the hair, neck, orbits and ears have been shaded orange and eliminated from the registration process. A) anterior, oblique and left sided profile of a male subject with a left sided maxillary defect; B) anterior, oblique and left sided profile of a female subject also with a left sided maxillary defect.

Figure 2. Effect of the obturator on restoring facial form in two subjects. A) the same subject outlined in Figure 1A with the left sided maxillary defect showing photographs of the subject with and without the obturator in place and the difference image generated. The scale of the difference image is  $\pm 8\text{mm}$ . The area in which the obturator restores facial form can be clearly identified on the left side of the face; B) the same subject outlined in Figure 1B with the larger left sided maxillary defect showing photographs of the subject with and without the obturator in place and the difference image generated. The scale of the difference image is  $\pm 16\text{mm}$ . The area in which the obturator restores facial form can be clearly identified on the left side of the face and extends a small distance across the midline.

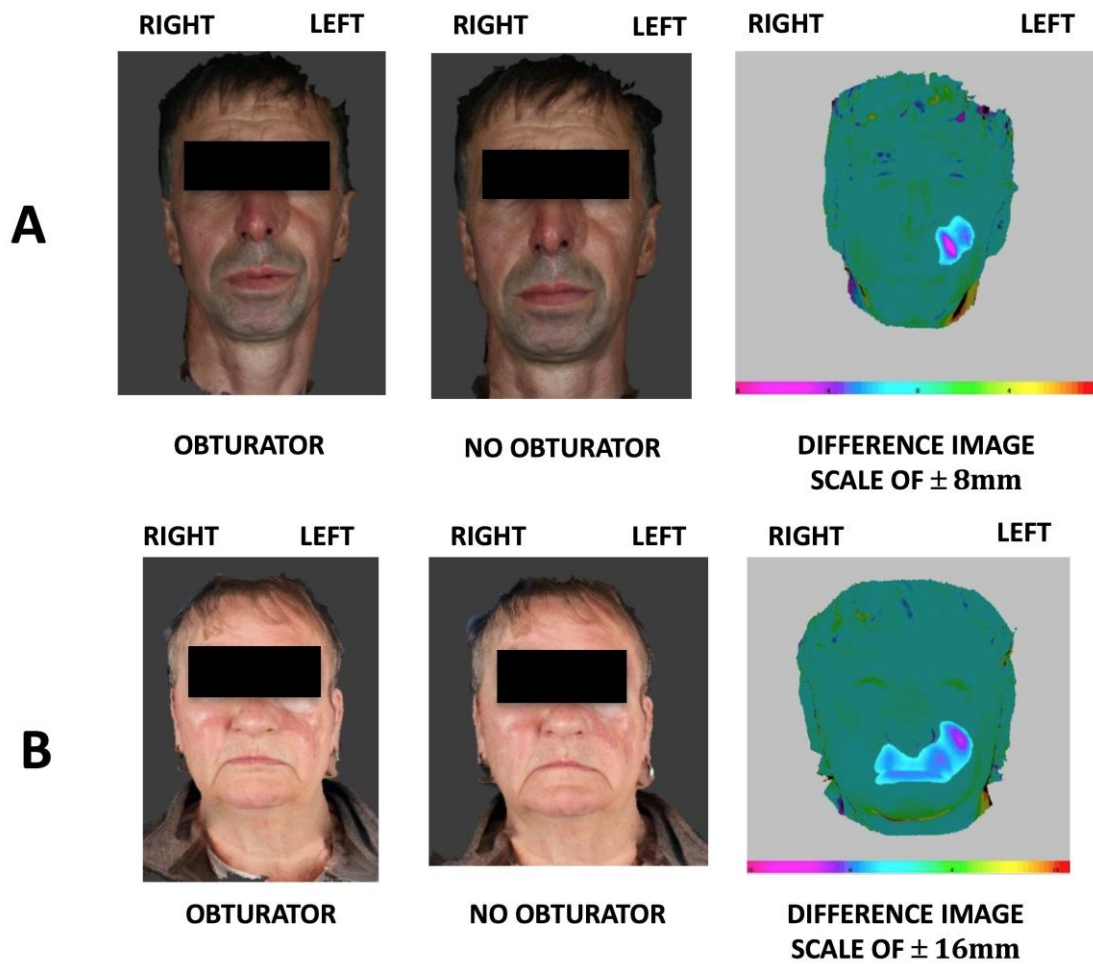
Figure 3. Clustered bar chart to show the reproducibility of surface area measurements for each subject showing the mean of registration 1, readings 1 and 2 (solid bars) versus the mean of registration 2, readings 1 and 2 (dotted bars).

Figure 4. Clustered bar chart to show the reproducibility of volume measurements for each subject showing the mean of registration 1, readings 1 and 2 (solid bars) versus the mean of registration 2, readings 1 and 2 (dotted bars).

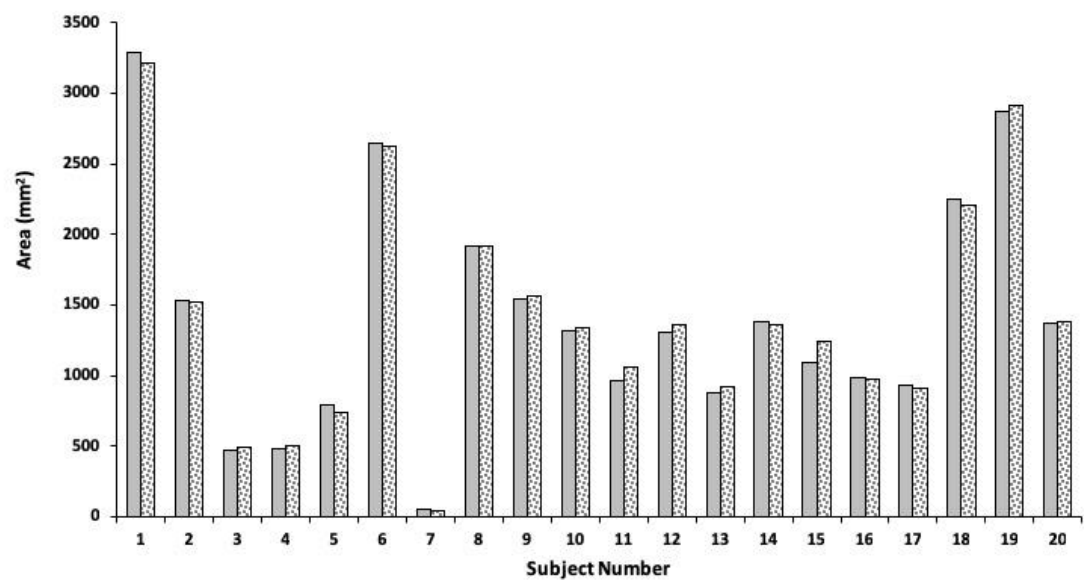
Figure 5. Bar chart to show the final calculated volume differences of the restored facial defects for each subject as defined by the colour coded difference images.







**REPRODUCIBILITY OF SURFACE AREA MEASUREMENTS FOR EACH SUBJECT  
MEAN OF REGISTRATION 1 READINGS 1 AND 2 VERSUS  
MEAN OF REGISTRATION 2 READINGS 1 AND 2**



**REPRODUCIBILITY OF VOLUME MEASUREMENTS FOR EACH SUBJECT**  
**MEAN OF REGISTRATION 1 READINGS 1 AND 2 VERSUS**  
**MEAN OF REGISTRATION 2 READINGS 1 AND 2**

